

Oscillator Models for the Universe and Dark Energy

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Abstract

We consider two situations that can be modeled by oscillators. First we show that the universe itself is a normal mode of Planck scale oscillators. Next we show that a background Zero Point Field or dark energy can be modeled by electromagnetic oscillators. This in turn leads to an observable “fluctuational” current in a solenoid.

1 Planck Scale Oscillators

In an earlier communication [1], it was argued that a typical elementary particle like a pion could be considered to be the result of 10^{40} evanescent Planck scale particles. The argument was based on random motions and also on the modification to the Uncertainty Principle. We will now consider the problem from a totally different point of view, which not only reconfirms the above result, but also enables an elegant extension to the case of the entire universe itself.

We first consider an array of N particles, spaced a distance Δx apart, which behave like oscillators, that is as if they were connected by springs. We then have [2, 3]

$$r = \sqrt{N\Delta x^2} \tag{1}$$

$$ka^2 \equiv k\Delta x^2 = \frac{1}{2}k_B T \tag{2}$$

where k_B is the Boltzmann constant, T the temperature, r the extent and k is the spring constant given by

$$\omega_0^2 = \frac{k}{m} \quad (3)$$

$$\omega = \left(\frac{k}{m} a^2 \right)^{\frac{1}{2}} \frac{1}{r} = \omega_0 \frac{a}{r} \quad (4)$$

We now identify the particles with Planck masses, set $\Delta x \equiv a = l_P$, the Planck length. It may be immediately observed that use of (3) and (2) gives $k_B T \sim m_P c^2$, which ofcourse agrees with the temperature of a black hole of Planck mass. Indeed Rosen had shown that a Planck mass particle at the Planck scale can be considered to be a universe in itself [4].

We now use the fact alluded to that a typical elementary particle like the pion can be considered to be the result of $N \sim 10^{40}$ Planck masses (Cf.ref.[1]). Using this in (1), we get $r \sim l$, the pion Compton wavelength as required. Further, using (2), (3) and (4), we get for a pion,

$$k_B T = \frac{m^3 c^4 l^2}{\hbar} = m c^2,$$

which ofcourse is the well known formula for the Hagedorn temperature for elementary particles like pions. In other words, this confirms the conclusions in [1], that we can treat an elementary particle as a series of some 10^{40} Planck mass oscillators.

However it must be observed from (2) and (3), that while the Planck mass gives the highest energy state, an elementary particle like the pion is in the lowest energy state. This explains why we encounter elementary particles, rather than Planck mass particles in nature. Infact as already noted [5, 6], a Planck mass particle decays via the Bekenstein radiation within a Planck time $\sim 10^{-42} \text{secs}$. On the other hand, the lifetime of an elementary particle would be very much higher.

Using the fact that the universe consists of $n \sim 10^{80}$ elementary particles like the pions, the question is, can we think of the universe as a collection of 10^{120} Planck mass oscillators? This is what we will now show. Infact if we use equation (1) with

$$N \sim 10^{120},$$

we can see that the extent $r \sim 10^{28} \text{ cms}$ which is of the order of the diameter of the universe itself. Next using (4) we get

$$n\hbar\omega_0^{(min)} \frac{l_P}{10^{28}} \approx m_P c^2 \times 10^{60} \quad (5)$$

which gives the correct mass of the universe. In other words the universe itself can be considered to be a normal mode of Planck scale oscillators.

2 Oscillators and Dark Energy

The existence of the Zero Point Field (ZPF) was realised even by Max Planck. In its later version it has come to be known as Quantum Vacuum, and lately it has been possible to identify it with the mysterious dark energy. The Zero Point Field arises because of the fact that though classically, an oscillator in the ground state has zero energy, Quantum Mechanically, owing to the uncertainty principle, there is an energy fluctuation about the zero energy level.

Interestingly there have been two schools of thought. Zero Point Field, according to Quantum theorists is a secondary effect arising from the already present oscillators. However according to what has come to be known as Stochastic Electrodynamics, the ZPF is primary, and infact Quantum Mechanics can be deduced therefrom. This is a chicken and egg situation.

Recently the ZPF has come into focus once again because of the observed ever expanding, accelerating feature of the universe. In other words there is a large scale repulsion represented by a cosmological constant Λ once invented and then rejected by Einstein, and this cosmic repulsion could be attributed to a mysterious all pervading dark energy, which can be identified with the ZPF: this could be the mechanism which drives the cosmic expansion and acceleration (Cf.ref.[7]) for a review).

Two of the earliest realisations of the ZPF were in the form of the Lamb shift and the Casimir effect.

In the case of the Lamb shift, as is well known, the motion of an orbiting electron gets affected by the background ZPF. Effectively there is an additional field, over and above that of the nucleus. This additional potential, as is well known is given by [8]

$$\Delta V(\vec{r}) = \frac{1}{2} \langle (\Delta r)^2 \rangle \nabla^2 V(\vec{r})$$

The additional energy

$$\Delta E = \langle \Delta V(\vec{r}) \rangle$$

contributes to the observed Lamb shift which is $\sim 1000mc/sec$.

The essential idea of the Casimir effect is that the interaction between the ZPF and matter leads to macroscopic consequences. For example if we consider two parallel metallic plates in a conducting box, then we should have a Casimir force given by [9]

$$F = \frac{-\pi^2}{240} \frac{\hbar c A}{l^4}$$

where A is the area of the plates and l is the distance between them. More generally, the Casimir force is a result of the boundedness or deviation from a Euclidean topology of or in the Quantum Vacuum. These Casimir forces have been experimentally demonstrated [10, 11, 12, 13].

Returning to the ZPF as the ubiquitous dark energy, we observe that [14], a fluctuating electromagnetic field can be modelled as an infinite collection of independent harmonic oscillators. Quantum Mechanically, the ground state of the harmonic oscillators is described by

$$\psi(x) = \left(\frac{m\omega}{\pi\hbar} \right)^{1/4} e^{-(m\omega/2\hbar)x^2}$$

which exhibits the probability for the oscillator to fluctuate, mostly in the region given by

$$\Delta x \sim (\hbar/m\omega)^{1/2}$$

An infinite collection of such oscillators can be modelled by

$$\psi(\xi_1, \xi_2, \dots) = \text{const.} \exp[-(\xi_1^2 + \xi_2^2 + \dots)],$$

which gives the probability amplitude for an electromagnetic field configuration $B(x, y, z), \xi_1$, etc. being the Fourier coefficients. Finally, as a consequence there is a fluctuating magnetic field given by

$$B = \frac{\sqrt{\hbar c}}{l^2} \tag{6}$$

where l is the extent over which the fluctuation is measured. Further these fluctuations typically take place within the time τ , a typical elementary particle Compton time (Cf.ref.[1]). This begs the question whether such ubiquitous fields could be tapped for terrestrial applications or otherwise.

We now invoke the well known result from macroscopic physics that the current in a coil is given by

$$i = \frac{NBA}{R\Delta t} \quad (7)$$

where N is the numer of turns of the coil, A is its area and R the resistance. Introducing (6) into (7) we deduce that a coil in the ZPF would have a fluctuating electric current given by

$$i \approx \frac{NA}{R} \cdot \frac{e}{l^2\tau} \quad (8)$$

In principle it should be possible to harness the current (8). While this current is small, if we have a superconductor, then R would be very small and the current would be much larger. The question is, whether such an application is possible, on the earth or in an orbiting space craft, for example. Finally, it may be remarked that the usual ZPF of Quantum Theory leads to an unduly large cosmological constant [15]. However, in the model described in [5, 7], we get the observed small cosmological constant.

References

- [1] B.G. Sidharth, Found. of Phys.Lett., 15 (6), December 2002, 577-583.
- [2] Y. Jach NG and H. Van Dam, Mod.Phys.Lett.A., 9 (4), 1994, p.335-340.
- [3] D.L. Goodstein, "States of Matter", Dover Publications Inc., New York, 1985, p.160ff.
- [4] N. Rosen, Int.J.Th.Phys., 32 (8), 1993, p.1435-1440.
- [5] B.G. Sidharth, "Chaotic Universe: From the Planck to the Hubble Scale", Nova Science Publishers Inc., New York, 2001, p.65ff.
- [6] B.G. Sidharth, Chaos Solitons and Fractals, 12 (1), 2000, 173-178.
- [7] B.G. Sidharth, Chaos, Solitons and Fractals, 16(4), 2003, p.613-620.
- [8] J.D. Bjorken, and S.D. Drell "Relativistic Quantum Mechanics", McGraw Hill, New York, 1964, p.39.

- [9] L. de la Pena and A.M. Cetto, Found.of Phys., Vol.12, No.10, 1982, p.1017-1037 and references therein.
- [10] V.N. Mostepanenko and N.N. Trunov, Sov.Phys.Usp., Vol. 31, No.11, 1988, p.965-987.
- [11] V.B. Svetovoy and M.V. Lokhanin, Mod.Phys.Lett.A., Vol.15, Nos.22 & 23 2000, p.1437-1444.
- [12] P.K. Anastasovski, T.E. Bearden, et al., Found.of Phys.Lett., Vol.13, No.3, 2000, p.289-296.
- [13] A. Bulgac and A. Wirzba, Phys.Rev.Lett., Vol.87, No.12, 2001, p.120404-1- 120404-4.
- [14] C.W. Misner, K.S. Thorne and J.A. Wheeler, "Gravitation", W.H. Freeman, San Francisco, 1973, pp.1180ff.
- [15] S. Weinberg, Phys.Rev.Lett., 43, 1979, p.1566.